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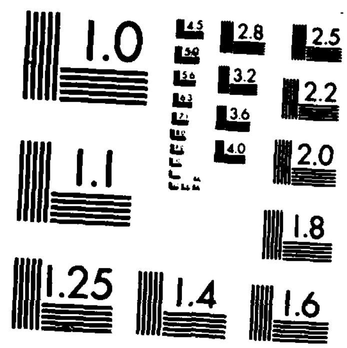

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HUMAN FACTORS TECHNOLOGIES:
PAST PROMISES, FUTURE ISSUES

Earl A. Alluisi

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This position paper discusses what the author views as major issues confronting the human factors profession. The small size of the human factors work force, relative to the hardware/software engineering work force, is fundamental to the several issues discussed: How can we generate leverage? How can we use computer technologies to make a highly leveraged impact on design? How can we construct or generate applicable data and databases for the computer-based leverage we need? The paper addresses the resolution of these issues with some specific examples. Keywords:

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SUMMARY

This position paper discusses what the author views as major issues confronting the human factors profession. The small size of the human factors work force, relative to the hardware/software engineering work force, is fundamental to the several issues discussed: How can we generate leverage? How can we use computer technologies to make a highly leveraged impact on design? How can we construct or generate applicable data and databases for the computer-based leverage we need? The paper addresses the resolution of these issues with some specific examples.

HUMAN FACTORS TECHNOLOGIES: PAST PROMISES, FUTURE ISSUES

A SYSTEM can be characterized as an integration of properly interfacing things, people, and ideas. A SYSTEM can be depicted as a circle with three slices representing the component things, people, and ideas, three radii representing the interfaces, and a circumference representing their integration.

Past Promises: To Deal with Systems and System Designs

The words SYSTEMS and SYSTEM DESIGNS are used frequently in succeeding paragraphs. Indeed, they are used frequently whenever human factors specialists meet and talk. The concepts are central not only to the theme of this chapter, but also to the roles and functions of the human factors specialist.

For example, in the most recent Annual Review of Psychology chapter on "Engineering Psychology," Wickens and Kramer (1985, p. 307) characterized engineering psychology as "the study of human behavior with the objective of improving human interaction with systems." They went on to say that the "field is partner to at least three related disciplines, overlapping but not synonymous." They listed the three disciplines as follows:

1. human factors engineering, which "considers the role of human limits, constraints, and characteristics in system design" and the ultimate goal of which is "to improve system design" (p. 307),

2. ergonomics, which is "nearly synonymous with human factors and has ... a major component related to work physiology" (p. 308), and

3. human skilled performance, which "addresses issues of performance in complex tasks [but] does not necessarily aim its findings toward the production of better systems" (p. 308).

The definitions may seem somewhat awkward, and their distinctions a bit "fuzzy," but they are essentially accurate. We may work in a "fuzzy" field, but we share one common element: We all have the goal of impacting system designs to improve human interactions--i.e., to produce "better" systems.

This emphasis on SYSTEMS and SYSTEM DESIGN is not new. It appears in earlier definitions. For example, when Paul Fitts (1958) wrote the first Annual Review of Psychology chapter on "Engineering Psychology" nearly three decades ago, he divided the field into two parts, the professional and the scientific:

1. The professional aspect applies "psychological knowledge to the design of human tasks, man-operated equipment, and man-machine systems, usually in collaboration with engineers" (p. 267).

2. The scientific aspect provides the supporting data that "are contributed mainly by conventional areas of experimental psychology, such as vision, hearing, perception, and learning" (p. 267).

According to Fitts (1958), then, the PROFESSIONAL aspect of our field is concerned with what we today call ergonomics, human factors, or engineering psychology APPLICATIONS. The SCIENTIFIC aspect provides the human-centered BASIC DATA for those applications.

The emphasis was continued in subsequent review chapters. For example, Melton and Briggs (1960) stressed "the identification of human performance functions which are relevant, not only to the initial design (or redesign) of equipment components of man-machine systems, but also to the determination of operational procedures and work environments for the human operator" (p. 71). Chapanis (1963) thoroughly embedded the emphasis on SYSTEMS and SYSTEM DESIGNS throughout his review. He noted that the application (human factors engineering or human engineering) "is an amalgam of several technical fields: psychology, physiology, anthropometry, toxicology, medicine, biology, and industrial engineering among others" (p. 287).

[It is interesting to note that Chapanis called attention to issues such as the gap between researchers and appliers, methodology, and the quality of our work. The researchers, he observed, tend to be academicians "primarily concerned with the teaching and discovery of basic information and principles about man's behavior in a machine environment" (p. 305). On the other hand, the appliers work in industry where managers are much more impressed by "illustrations of genuine machine systems that have actually been improved" than by "recitations of research findings, however dependable these may be" (p. 306). He stressed the (still valid) need for quality and for "the proper validation of the results of our recommendations" (p. 306).]

Poulton (1966) said that the "aim of engineering psychology is not simply to compare two possible designs for a piece of equipment, but to specify the capacities and limitations of the human, from which the choice of the better design should be deducible directly" (p. 178). He broadened the definition of our field further by calling it the "experimental psychology of man in the complex technology of the mid-twentieth century" (p. 178).

A decade later, and a decade ago, Alluisi and Morgan (1976) commented on the trend toward broadening the concept of engineering psychology. The practice, they said, had evolved into "the human factors or human resources applications of the data, methods, theories, and philosophies of experimental psychology in the design, maintenance, operation, and improvement of all kinds of operating systems in which humans are components" (p. 306).

Thus, by whatever name we are called, from our very beginning even to the present day, the ergonomics, human factors, or engineering psychology field has promised (a) to be a profession and a discipline, and (b) to address SYSTEMS and SYSTEM DESIGNS issues. To achieve these goals, we have (a) established appropriate mechanisms, such as scientific societies, professional associations, journals, and other publications, and (b) attempted to address the issues in our research by collecting data that are relevant and applicable, and in our applications by affecting (improving) systems and system designs. With regard to the latter, it is appropriate to ask, "How well are we doing?"

Status: Dealing with Systems and System Designs

In a recent issue of the Human Factors Society Bulletin, Hendrick (1986) summarized the findings of a project "to review human factors in the Air Force and the Department of Defense" (p. 4). The study, as yet unpublished, was conducted by Air Force personnel and a team of consultants. A figure or diagram was used to model the structure of human factors applications in the military setting. As Hendrick pointed out, the taxonomic scheme and structure modeled by the diagram "is probably applicable to human factors efforts in all current technological settings" (p. 4). The model is described as follows:

Picture four rows showing four levels or kinds of work (and funding). The top row represents the science base built by basic research. The next row represents the human-machine technology base supported by exploratory and non-systems (or component) advanced development. The third row represents the human-machine-mission applications that characterize the system design process

supported by system-related advanced development and engineering development. Finally, the bottom row represents the human-machine-mission products that are the systems which are produced, procured, and fielded for operational use.

At the science base level, three broad disciplinary families provide relevant knowledge; namely, the behavioral, biomedical, and physical sciences. At the next level, subsets of those disciplines are primarily involved: (a) from the behavioral sciences on the left, personnel and training scientists are involved in developing human resource technology for the human base; (b) from the physical sciences on the right, hardware engineering scientists are concerned with machine development technology for the machine base; and (c) from all three science-base families in the center, human factors engineering scientists are involved in developing human-machine integration technology for the human-machine base.

At the next level--the level of applications--the three technology bases are fused into two separate, but coordinated, developments: (a) one for the hardware systems by hardware/software engineers, and (b) the other for the training systems by personnel and training specialists. Human factors engineers, according to the model, are involved in both.

At the final level, the system is produced, procured, and fielded for operational use. There are at least five major parts or subsystems to this level; namely, (a) personnel, (b) training systems and equipment, (c) system hardware/software, (d) logistics support, and (e) system facilities.

Although somewhat complex, this conceptualization, and the diagram used by Hendrick (1986) to represent it, provide an accurate model of the current acquisition process. Yet, NOWHERE does the model show the process dealing with the design of a FULL SYSTEM--a system consisting of the integration of properly interfaced things, people, and ideas! Today, engineers still design and build THINGS, not systems. Today, the acquisition process still develops and procures the thing-parts of systems, not whole systems.

It would appear that neither our profession nor our discipline is delivering adequately on our long-standing promise to deal with systems and system designs. We shall face certain issues in any attempt to do so in the future.

Future Issues

Our Numbers. The first issue is related to the size of the human factors work force relative to the hardware/software engineering work force. Data taken from the Statistical Abstract of the United States (1986), Knowles and Vaughan (1986), and Sanders, Bied, and Curran (1986) yield the results shown in Tables 1, 2, and 3.

Table 1. Number of Engineers and Human Factors Specialists (in thousands)

	Engineers	Human Factors Specialists
Total USA	2,086	4 (0.2%)
USA Employed	1,627	3 (0.2%)
Private Industry/ Business	1,016	2 (0.2%)
Academic/Government	611	1 (0.2%)

Table 2. Work/Site Distribution of Human Factors Specialists in USA

Work/Site	Number	Percent
F/M/A in USA[a]	2,991	100%
Academia	529	17.7
Government	589	19.7
Industry	1,161	38.8
Business	565	18.9
Other	147	4.9

[a]Fellows, Members, Associates

From Table 1, it appears that human factors specialists constitute about two-tenths of one percent of the engineering population of the United States. From Table 2, it appears that approximately 18% of the nearly 3,000 human factors specialists gainfully employed in the USA are in academic institutions. Furthermore, it appears from Table 3 that of the 2,462 (82.3% of the 2,991) not in academic institutions, the majority are involved in management, staff work, or other activities. Slightly fewer than a quarter (17.5% + 7.0% = 24.5%) are engaged in line or line-supervisory human factors engineering. Put another way, there are only about 600 human factors specialists (431 + 172 = 603) doing the applications work of our profession in the United States today.

Table 3. Distribution of Non-Academic Human Factors Specialists in USA

Activity	Number	Percent
Non-Academic	2,462	100%
Management	665	27.0
Staff Work	899	36.5
Other	295	12.0
Supervisory	431	17.5
Line	172	7.0

These data identify the first of the future issues; namely, that of how a relatively few human factors specialists will be able to impact SYSTEMS AND SYSTEM DESIGNS to any substantial degree. It is apparent that resolution of this issue will require either great increases in our numbers (which is not really likely), or the development of appropriate techniques to leverage our inputs.

Computer-Based Leverage. A second future issue arises from computer technologies and their potentials for providing the leverage necessary to resolve the "numbers" issue.

Askren (1985) has addressed this potential in describing what he sees as new roles for the human factors specialists in equipment design. He identified these in four domains: (a) applied methods development (design rules, models, databases, etc.); (b) design participation (near-real-time and interactive); (c) research and development (in areas such as decision aiding and task analysis); and (d) education and skills development (e.g., in computer graphics, computer-aided design software, database management systems, human factors databases, design trade-off methodologies, and evaluation procedures).

Data and Databases. If the first future issue ("How can we generate the leverage?") gives rise to the second ("How can we use computer technologies to make a highly leveraged impact on systems and system designs?"), then the second gives rise to the third, "How can we construct or generate applicable data and databases for the computer-based leverage we need?"

The "applicable data and database" part of the issue is not new, but the computer leverage part is. For example, nearly 25 years ago, Martin and Alluisi (1963) observed:

> Only in a relatively few instances are timely, useful, properly quantified human-factors data available for direct application by the design engineer (p. 1). [As a result] the approach being used by most human-factors engineers is that of mocking-up the task, setting the reasonable (or allowable) parameters, and collecting data to answer the design engineer's question....This procedure is, however, quite inefficient. It means that the same questions...come up again and again around the country....[With a little more work, we could] provide a relatively complete function or table of values that could be put in the literature to be used in answering a similar question with different parameters. (p. 5)

The new part of the requirement is that the human factors engineering data and databases would have to be in forms compatible with the computer-aided design and computer-aided manufacturing (CAD/CAM) practices of industry.

Resolutions of the Future Issues

Data and Databases. Six shortcomings, or deficiencies, of human factors engineering data were identified by Martin and Alluisi (1963) 25 years ago. These are still with us today: (a) There are insufficient data for engineering; (b) few data exist on the human performance impacts; (c) the applicability to design of what data there are is not well defined; (d) averages, rather than individual data or percentile ranges, are cited in most cases; (e) the interaction of factors is often ignored; and (f) a single, unified, and comprehensive human-factors engineering design database is badly needed.

The last point cannot be overemphasized. Data that cannot be accessed and applied by design engineers in the course of their work are little better than no data at all. Martin and Alluisi (1963) are still correct in saying:

> There is need for research that measures the abilities of man in much the same manner that the strength of materials is measured under various conditions by the metalurgist... man's 'strengths'--or the things he can do, his performance abilities--should be measured under conditions that range from the lowest to the highest...[and] tabulated in engineering formats, with parameters and units of measure that are compatible with engineering design practices. (p. 5)

There may be a resolution of this issue on the horizon--at least for part of the needed data. The recently published first volume of a reference handbook (Boff, Kaufman, & Thomas, 1986) provides "an in-depth presentation of human perception, information processing, and performance excluding broad coverage of traditional ergonomics and systems design issues" (p. xi).

More importantly, the handbook is the first product of the Integrated Perceptual Information for Designers program, which has as its objective the "consolidation and effective communication of perceptual and human performance data for design of human/machine systems" (p. xi). Although the handbook was designed to stand alone, we are promised that "it will be followed by the

Engineering Data Compendium: Human Perception and Performance and, with continued support, an automated database" (p. xi).

The issue will be resolved when the right kind of database is made available: a human factors engineering database with units of measure and formats that can be used by the design engineers "at the bench." Without a doubt, a great deal of work is still needed to produce that database, but without it, the "sunk-cost" efforts that have already been expended in producing the handbook will be essentially worthless to any except academic interests.

Computer-Based Leverage. CAD/CAM capabilities are revolutionizing the design and development process. The enabling technologies include the explosion in computer storage capacities, computer graphics, and distributed system networking. Industry implementation of computers for performance engineering and drafting is widespread, and rapidly approaching universal. This now permits the human factors specialist to work in real time with designers from a CAD workstation. A quite successful application has been documented by the General Dynamics Convair Division (1984) in a CAD study of a ground-launched cruise missile turbine system.

The impact is being observed even today. For example, rather than having to build a mock-up to test the accessibility of parts for maintenance activities, the test can be made on the computer screen before a single line of the design is set to paper. The mock-up is fast becoming an unnecessary expense.

This is not a new process for the human factors specialist, but rather, a more efficient application of the past (and still current) process. Thus, the computer graphics replace the mock-up. By so doing, the "empirical" test is made prior to the final design, thus making any needed modifications much easier and less costly to effect. Also, the computer-aided system is much more amenable to showing interactions, for in a three-dimensional graphic display, there are essentially an infinite number of viewpoints that can be observed from any number of points of view (accessibility, maintainability, vulnerability, etc.). The utility, and eventual impact, of the leverage provided by the CAD/CAM movement in industry will be limited only by our numbers as long as the process is not changed and the human factors specialist must sit at the computer to make the inputs for the human factors engineering considerations.

Our Numbers. A change in the process will be needed to resolve the issue of the small number of human factors specialists relative to the number of engineers. For example, doubling our numbers would take us only to four-tenths of one percent of the engineering community. Increasing our numbers by an order of magnitude would take us only to two percent. And there are still additional areas that must be covered in the design process if we are to achieve our goal of dealing with full systems and system designs.

The greatest need here is for the cited relevant human factors engineering databases that are directly usable by the design engineers. Once those are available, the human factors engineering input will no longer be dependent solely on what the two-tenths of one percent can do. Design engineers could then design full systems that include proper consideration not merely of the hardware and software, but also of the "liveware" and "mindware"--the people and idea parts--of systems. The role of the human factors specialist would then be one of oversight and identification (and fulfillment) of data and database needs.

But, be not deceived! There is much to be done before we arrive at that world. There are additional technologies, heretofore not regarded as core, that will need to be developed before we can construct the databases required to permit even human factors specialists (much less design engineers) to address the design of full systems. Specifically, there are the manpower, personnel, and training technologies and data, which to a considerable extent do exist today, but not as human factors engineering databases.

This issue will be resolved through the evolution of a unified engineering system in which (a) ENGINEERS address FULL SYSTEM design (integration of the interfacing "wares," hardware, software, liveware, and mindware--or all the things, people, and idea parts of a full system); (b) ENGINEERS consider all the "ilities" (survivability, reliability, interoperability, maintainability, etc., and to include manpower availability, and trainability), and their trade-offs, as part of the FULL SYSTEM design process; and (c) ergonomics and human factors RESEARCHERS provide the enabling human factors *engineering* databases.

Engineers design holes in panels through which maintenance technicians reach things; engineers do not design the hands of the technicians. But anthropometric databases that give the sizes of human hands are what we have provided. What the design engineer needs for direct application is an "accessibility" database--a database that shows the sizes of holes through which different percentiles of maintenance technicians can reach with their hands, and the impacts or trade-offs associated with the different hole sizes.

Trade-off nomographs should relate the sizes of holes to the numbers or percentages of the relevant populations that are included or excluded (and the impact), and not merely show the sizes of holes that "fit" a range from the fifth percentile female through the ninety-fifth percentile male. Engineers know something of structural integrity and the impact of hole size on it. They can compute the trade-off in terms of materials, thickness, weight, cost, etc.--i.e., on the "things" part of the system. We need to develop comparable data and databases to provide engineers the impacts of accessibility options (hole sizes) on the full system, to include the "people" parts of the system.

We shall also need to provide databases relating the aptitude/training/job- and task-difficulty variables and interactions. The list of examples could be extended for several more pages. But the point has been made. We have a lot to learn, and a lot of data and databases to construct, to support the sort of unified engineering system that would resolve the issue and permit, finally, the human factors technologies to fulfill their past promises.

Summary

The major points of this paper can be summarized briefly as follows:

1. A SYSTEM is an integration of properly interfacing things, people, and ideas.

2. The past promises of the human factors technologies (both profession and discipline) have been to improve SYSTEMS and SYSTEM DESIGNS.

3. Today, neither human factors specialists nor design engineers are dealing with FULL SYSTEMS or FULL SYSTEM DESIGNS.

4. There are few human factors specialists (0.2%) relative to the engineering population, but computers can provide LEVERAGE through CAD/CAM applications.

5. Broadly construed human factors ENGINEERING databases are needed to take advantage of the potential leverage of CAD/CAM applications.

6. Perhaps, the time, the "can-do" Zeitgeist, is NOW! We need (a) to expand the technologies covered, including all people-related "ilities" databases such as personnel availability and trainability; (b) to help develop a viable unified engineering system; and (c) to help engineers really design systems, not merely the hardware/software parts of systems.

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